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Maritimes Region
Canadian Science Advisory Secretariat
Science Advisory Report 2011/045

ASSESSMENT OF NOVA SCOTIA (4VWX) SNOW CRAB

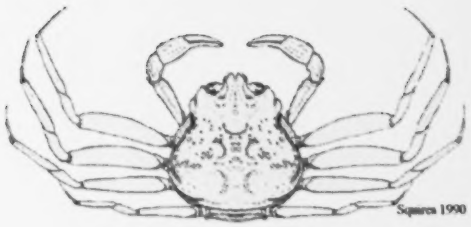


Figure 1. Map of the Scotian Shelf and Crab Fishing Areas (CFA).

Context:

Snow crab have been a dominant macro-invertebrate in the Scotian Shelf Ecosystem (SSE) since the decline of the groundfish. They are observed in large numbers in deep, soft-bottom substrates ranging from 60 to 280 m and at temperatures generally less than 6°C. The SSE snow crab are on the southern-most extreme of their spatial distribution in the Northwest Atlantic.

The fishery has been in existence since the early 1970s in Nova Scotia. The management of the snow crab fisheries in the SSE was initially based on effort controls (season, license, trap limits) from 1982 to 1993 with harvesting during June-November of hard-shelled males larger than 95 mm CW (carapace width). Additional management measures were introduced from 1994 to 1999: IBQs (individual boat quotas), TACs (total allowable catches), 100% dockside monitoring, mandatory logbooks and at-sea monitoring by certified observers. In 2005, many Crab Fishing Areas (CFAs) and subareas were merged with the resulting divisions being N-ENS (formerly CFAs 20-22), S-ENS (formerly CFAs 23, 24), and 4X (Figure 1).

In support of the fishery, DFO Maritimes Fisheries and Aquaculture Management requests from DFO Science an annual assessment of resource status. This document is a scientific overview of the assessment. An assessment of the status of 4VWX snow crab is made from fishery independent surveys using indicators of abundance, reproductive potential, recruitment, and exploitation rates. Commercial catch rates and other fishery statistics are reported. Harvest advice for the next year is provided.

SUMMARY

- Landings in 2010 for N-ENS and S-ENS were 576 and 13,150 t, respectively, and they were 229 t in CFA 4X for the 2009/10 season, representing increases of 0%, 22% and 0% relative to the previous year.

- Total allowable catches (TACs) in 2010 were 576, 13,200 and 230 t in N-ENS, S-ENS and CFA 4X. In 2009, they were 576, 10,800, and 346 t.
- Non-standardised catch rates in 2010 were 55.0 kg/trap haul and 102.5 kg/trap haul in N- and S-ENS, and 36.0 kg/trap haul in 4X in 2009/2010 – representing a decrease of 27%, an increase of 14% and an increase of 27%, respectively, relative to the previous year.
- The shift towards earlier fishing seasons appears to have improved soft shell crab handling rates in both N- and S-ENS. In N-ENS, the soft-shelled crab discard declined from 6.6% in 2009 to 3.5% in 2010. In S-ENS, soft-shell handling decreased from 16% in 2009 to 7.7% of the Total allowable catch in 2010. Soft-shell discard rates in CFA 4X are very low.
- In N-ENS, the post-fishery fishable biomass of snow crab in 2010 was 2,810 t (95% CI: 2,180 to 3,780 t; relative to 2,790 t (95% CI: 2,220 to 3,840 t) in 2009. In S-ENS, the post-fishery fishable biomass of snow crab was estimated to be 48.5×10^3 t (95% CI of: 32.2 to 77.9×10^3 t) relative to 49.3×10^3 t (95% CI of: 33.2 to 79.3×10^3 t) in 2009. In CFA 4X, the pre-fishery fishable biomass was 930 t (with a 95% CI of 590 to 1,440 t), relative to 1,070 t (95% CI of 640 to 1,730 t) in 2009/2010, representing a decrease of 13%.
- The leading edge of the main recruitment pulse of male crab detected in the mid-2000s first entered fishable sizes in 2007 and full entry to fishable sizes is expected in 2011/2012. Positive signs of adolescent crab suggest continued recruitment to the fishery for the next 2 to 3 years in N- and S-ENS. Recruitment beyond 2-3 years is potential due to the existence of animals in the 40-60mm size classes in S-ENS. These size classes are not observed in N-ENS. 4X currently shows a lack of adolescent crab recruiting to the fishery in next 3-4 years.
- Egg production remains above historic means though less than the peak observed in 2007/2008. Egg production is expected to begin to decline below historic means due to a lack of immature female crab between 30-60 mm, potentially affecting long-term recruitment patterns.
- High relative densities of predators of immature and soft-shelled snow crab were found in areas with high densities of immature snow crab. This adds uncertainty to the possible strength of future recruitment to the fishable biomass.
- Average bottom temperatures in 2010 were generally similar to those in 2009. The surface area of potential snow crab habitat was above the historical mean in all areas.
- By-catch levels, mostly of other crustacean species, are less than 0.014% of annual landings in ENS and approximately 0.17% in CFA 4X. By-catch has been extremely low in the historical record.
- Fishing mortality in N-ENS was estimated to be 0.19 (95% CI: 0.14, 0.24) or a harvest rate of 17.3%, unchanged relative to 2009. Good recruitment and significantly reduced soft-shell handling results in a positive outlook. Until a strong and persistent increase in fishable biomass is observed, long-term harvest rates between 10% and 20% is part of the strategy for sustainability in this fishery. A decreased or status quo harvest strategy is recommended.
- Fishing mortality in S-ENS was estimated to be 0.23 (95% CI: 0.15, 0.33) or a harvest rate of 20.5%, a small increase relative to F=0.20 in 2009. Good recruitment suggests a positive outlook; however, the capture of soft shell crab remains an important issue for this fleet. Long-term harvest rates between 10% and 30% are part of the strategy for sustainability in this fishery. A decreased or status quo harvest strategy is recommended.
- Fishing mortality in CFA 4X for 2009/2010 was estimated to be 0.22 (95% CI: 0.15, 0.33) or a harvest rate of 19.7%, relative to F=0.19 in 2008/2009. Long-term harvest rates between 10% and 30% are part of the strategy for sustainability in this fishery. As recruitment into the 2011/2012 season is uncertain, a decreased or status quo harvest strategy is recommended.

BACKGROUND

Species Biology

Snow crab (*Chionoecetes opilio*, O. Fabricius) is a subarctic species with a distribution from northern Labrador to near the Gulf of Maine. Habitat preference is for soft mud bottoms. Smaller crabs are found in more complex habitats with shelter. Commercial crab in large numbers are found at depths from 60 to 280 m and temperatures from -1 to 6°C on the Scotian Shelf. Temperatures greater than 7°C are known to be detrimental to snow crab. The primary food items of crab are shrimp, fish (capelin and lumpfish), starfish, sea urchins, worms, detritus, large zooplankton, other crabs, ocean quahaug, molluscs, sea snails and sea anemones. Predators of snow crab are halibut, skates (especially thorny skate), cod, seals, American plaice, squids, and other crabs. Crab in the size range of 3 to 30 mm CW are particularly vulnerable to predation, as are soft-shelled crab in the spring moulting season.

Fishery

The snow crab fishery in eastern Canada began in 1960 with incidental by-catches by groundfish draggers near Gaspé, Quebec. Its development was slow until the 1980s, when it began expanding rapidly to become one of the largest fisheries in Canada in terms of landings and landed value. On the Scotian Shelf, the fishery has been in existence since the early 1970s with landings at levels of 1,000 t. By 1979, this rose to 1,500 t, subsequent to which the fishery declined substantially in the mid-1980s. A large pulse of recruitment to the fishery was observed in 1986. Total landings increased to record-levels of approximately 10,000 t each year in the early 2000s (Figure 2). Landings in 2010 for N-ENS and S-ENS were 576 and 13,150 t, respectively, and they were 229 t in CFA 4X for the 2009/10 season, representing increases of 0%, 22% and 0% relative to the previous year. TACs (Total allowable catches) in 2010 were 576, 13,200 and of 346 t in N-ENS, S-ENS and CFA 4X (Figure 2, Tables 1, 2, and 3).

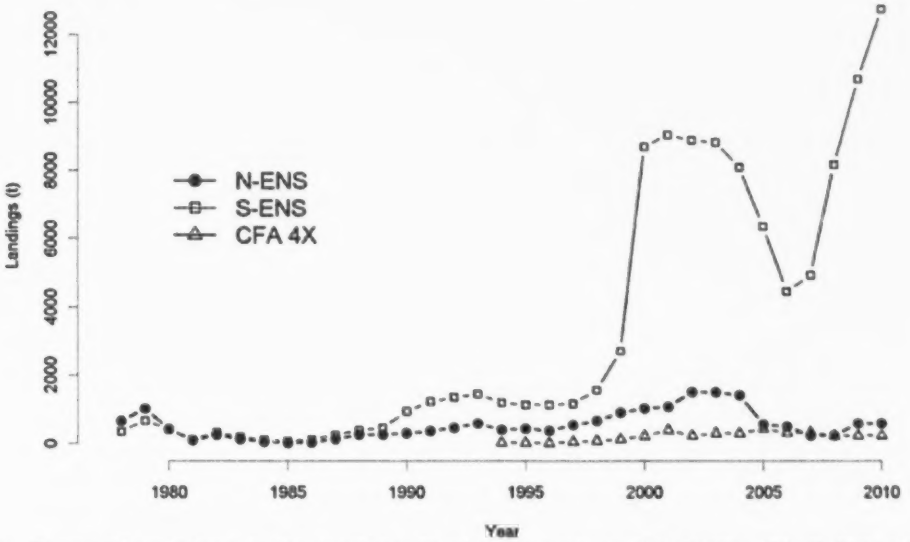


Figure 2. Temporal variations in the landings (t) of snow crab on the Scotian Shelf. Note the sharp increase in landings associated with large increases to TACs and a doubling of fishing effort in the year 2000. The landings follow the TACs with little deviation, so the TACs are not shown. For CFA 4X, the year refers to the starting year of the season.

Table 1. Summary of snow crab fisheries activity of N-ENS.

Year	Licenses	TAC (t)	Landings (t)	CPUE (kg/trap haul)	Effort (x1000 trap hauls)
1997	74	540	534	23.3	22.9
1998	74	660	657	41.6	15.8
1999	78	900	899	54.8	16.4
2000	79	1,015	1,017	68.3	14.9
2001	80	1,065	1,066	94.3	11.3
2002	80	1,493	1,495	101.0	14.8
2003	80	1,493	1,492	76.8	19.4
2004	79	1,416	1,418	60.6	23.4
2005	78	566	562	30.6	18.4
2006	78	487	486	35.6	13.7
2007	78	244	233	23.6	9.9
2008	78	244	238	33.7	7.0
2009	78	576	579	75.7	7.6
2010	78	576	576	55.0	10.5

Table 2. Summary of snow crab fisheries activity of S-ENS.

Year	Licenses	TAC (t)	Landings (t)	CPUE (kg/trap haul)	Effort (x1000 trap hauls)
1997	59	1,163	1,157	50.9	22.7
1998	67	1,671	1,558	68.9	22.6
1999	-	2,700	2,700	71.1	38.0
2000	158	8,799	8,701	85.0	102.4
2001	163	9,023	9,048	87.8	103.1
2002	149	9,022	8,891	111.7	79.6
2003	145	9,113	8,836	98.6	89.6
2004	130	8,241	8,022	105.6	76.0
2005	114	6,353	6,407	109.5	58.5
2006	114	4,510	4,486	90.9	49.4
2007	115	4,950	4,942	100.1	49.3
2008	115	8,316	8,253	96.1	85.9
2009	116	10,800	10,760	89.6	118.8
2010	116	13,200	13,150	102.5	128.3

Table 3. Summary of snow crab fisheries activity of CFA 4X.

Year	Licenses	TAC (t)	Landings (t)	CPUE (kg/trap haul)	Effort (x1000 trap hauls)
1997/08	4		42		
1998/09	4		70		
1999/2000	4		119		
2000/01	6		213		
2001/02	8	520	376		
2002/03	9	600	221	10.1	21.9
2003/04	9	600	289	12.7	22.8
2004/05	9	600	413	20.3	20.8
2005/06	9	337.6	306	28.6	10.8
2006/07	9	337.6	317	27.7	11.5
2007/08	9	230	220	18.1	12.1
2008/2009	9	230	229	28.4	8.0
2009/2010	9	230	229	36.0	6.4
2010/2011	9	346	*280		

* As of February 1, 2011, Season still in progress.

The spatial distribution of landings was focused on mid-shore and offshore areas in S-ENS and on "inside" (not Glace Bay Hole) area in N-ENS (Maps 1, 2). There was negligible effort on the offshore-slope areas in 2010. In 2010, a total of 10,500 and 128,300 trap hauls were applied in N- and S-ENS, respectively (Tables 1 and 2; Figure 3). In 4X, since 2007, fishers used industry standard large conical traps. In 2009/2010, a total of 6,400 trap hauls were applied in 4X (Table 3; Figure 3).

Non-standardized catch rates in 2010 were 55.0 kg/trap haul in N-ENS, 102.5 kg/trap haul in S-ENS, and 36.0 kg/trap haul in 4X in 2009/2010 – representing a decrease of 27%, an increase of 14% and an increase of 27%, respectively, relative to the previous year (Table 1-3; Figure 4).

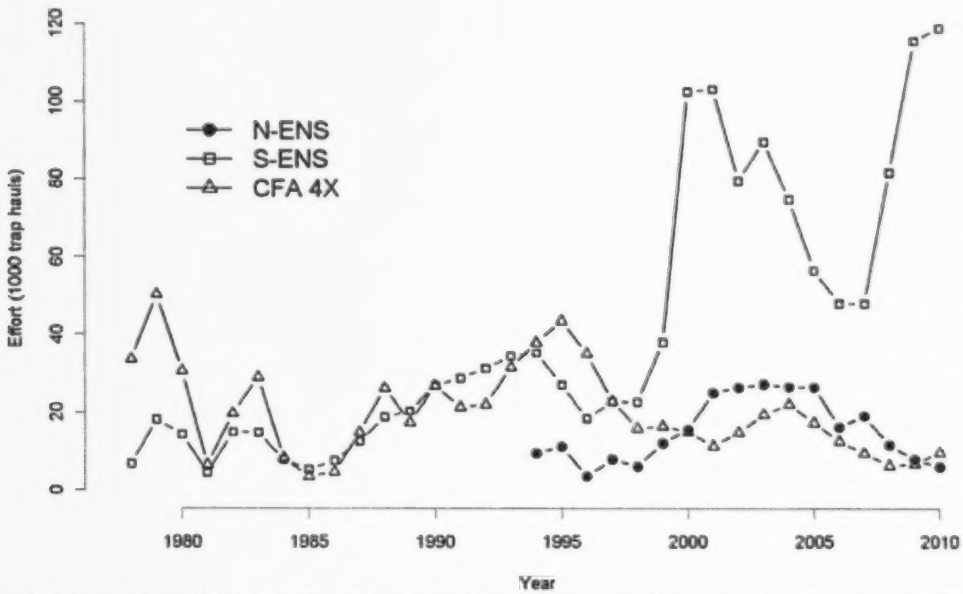


Figure 3. Temporal variations in the fishing effort, expressed as the number of trap hauls. Note the doubling of effort in the year 2000. For CFA 4X, year refers to the starting year of the season.

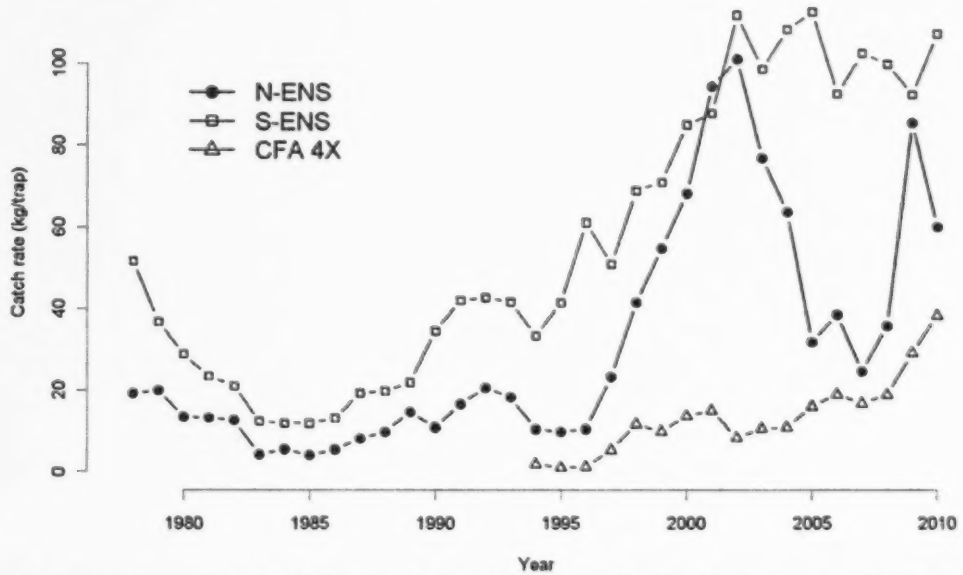


Figure 4. Temporal variations in catch rates of snow crab on the Scotian Shelf, expressed as kg per trap haul. Trap design and size have changed over time. No corrections for these varying trap-types nor soak time and bait-type have been made.

In N-ENS, CC1 (carapace condition 1) crab represented 3% of the total observed catch in 2010 and CC2 crab represented 2% of the total catch; both slight decreases from 2009 but drastic decreases from 2007. These decreases are largely attributable to the creation of a spring fishery since 2008. The proportion of the landings from the spring (as opposed to the summer) fishery has increased every year since 2008. Less than 3% of the catch were CC1 or CC2 in the

spring fishery (Figure 5). The occurrence of relatively few large animals (>110mm) may indicate that this fishery has become increasingly dependent on newly recruited animals.

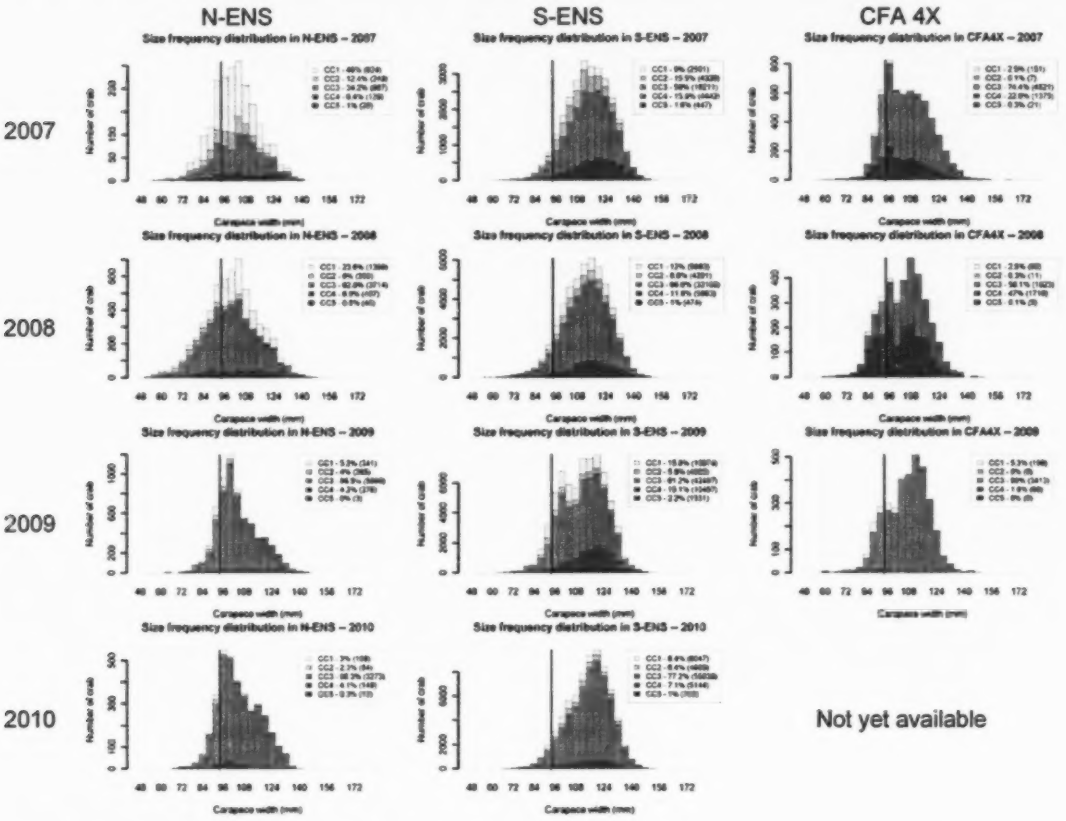


Figure 5. Size frequency distribution of all at-sea-observer monitored snow crab broken down by carapace condition. For CFA 4X, the year refers to the starting year of the season. Vertical lines indicate 95 mm CW, minimum legal commercial size.

In S-ENS, the moult structure of the catch observed at sea in 2010 demonstrated relatively few animals below minimum legal size (95mm CW) (Figure 5). Hard-shelled crab dominated the catch: 77% CC3 and 7% CC4. A reduction in the relative percent of CC4 crab from 2009 indicates continued recruitment of animals to the fishery. CC5 crab represented approximately 1% of the total observed catch. The abundance estimates of old male crab (CC5) has been stable in the historical record and below the detection limit on the Scotian Shelf surveys.

In CFA 4X, CC3 crab generally dominates the observed catch at 93%. However, the relative proportion of CC4 crab observed decreased from 21% in 2008 to 2% in 2009. This may be indicative of elevated exploitation and/or changing fishing grounds. CC1 crab represented a total of 5.3% of the total catch. CC2 and CC3 crab catches were negligible in the observed catches in 2009 in CFA 4X.

In N-ENS, the soft-shelled crab discard (% of total landings) declined from 6.6% in 2009 to 3.5% in 2010. This continues an improving trend in soft crab rates since 2007 in N-ENS when 111% of the landings were estimated to have been discarded as soft crab. In S-ENS, soft-shell handling decreased from 16% in 2009 to 7.7% of the TAC in 2010. The shift towards earlier

fishing seasons appears to have improved soft shell crab handling rates in both N- and S-ENS. Soft-shell discard rates in CFA 4X remain very low, in large part to a fall / winter fishery.

Figure 6. Location of traps sampled by at-sea observers which had 20% or greater soft crab. Lower soft shell catches over the season are reflected in the reduced number of locations with 20% or greater soft crab as compared to 2009.

ASSESSMENT

Stock Trends and Current Status

Fishable Biomass

The fishable biomass is defined as that segment of the snow crab biomass that is male, mature, larger than 95 mm CW and hard-shelled (with a durometer measure of 68 mm or greater).

In N-ENS, the post-fishery fishable biomass of snow crab in 2010 was 2,810 t (95% CI: 2,180 to 3,780 t; (Figure 7; Map 4) relative to 2,790 t (95% CI: 2,220 to 3,840 t) in 2009.

In S-ENS, the post-fishery fishable biomass of snow crab was estimated to be 48.5×10^3 t (95% CI of: 32.2 to 77.9×10^3 t) relative to 49.3×10^3 t (95% CI of: 33.2 to 79.3×10^3 t) in 2009 (Figures 41, 42, 45, 56).

In CFA 4X, the pre-fishery fishable biomass was 930 t (with a 95% CI of 590 to 1,440 t), relative to 1,070 t (95% CI of 640 to 1,730 t) in 2009/2010, representing a decrease of 13%.

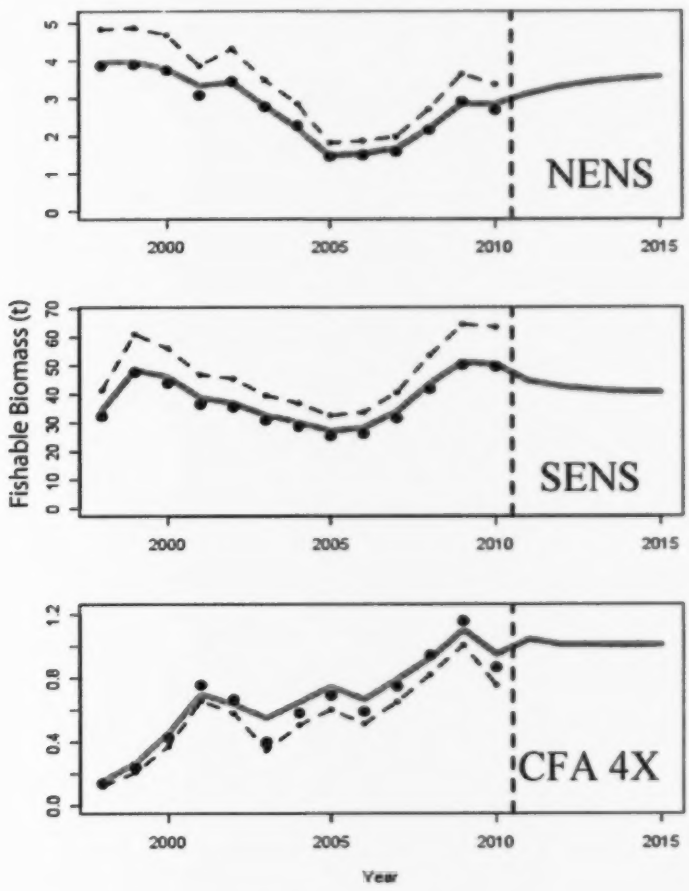


Figure 7. Fishable biomass index (the survey stratified index of fishable biomass; green dashed lines) and fishable biomass estimated from the biomass dynamics model (solid gray lines). Catchability-corrected fishable biomass estimates are presented (black dots). A five year projection assuming a constant exploitation strategy of 20% is also provided.

Recruitment

The index of recruitment (CC1 and CC2 crab, > 95 mm CW) to the fishable biomass since 2005 has been increasing in S- and N-ENS and extremely variable in CFA 4X (Figure 8). Most recruitment was observed in Misaine and Middle Banks (Map 5).

The leading edge of the main recruitment pulse of male crab detected in the mid-2000s first entered fishable sizes in 2007 (Figure 9a). Full entry to fishable sizes is expected in 2011/2012. Positive signs of adolescent crab suggest continued recruitment to the fishery for the next 2 to 3 years in N- and S-ENS. Recruitment beyond 2-3 years is possible due to the existence of animals in the 40-60mm size classes in S-ENS. These size classes are not observed in N-ENS. 4X currently shows a lack of adolescent crab recruiting to the fishery in next 3-4 years.

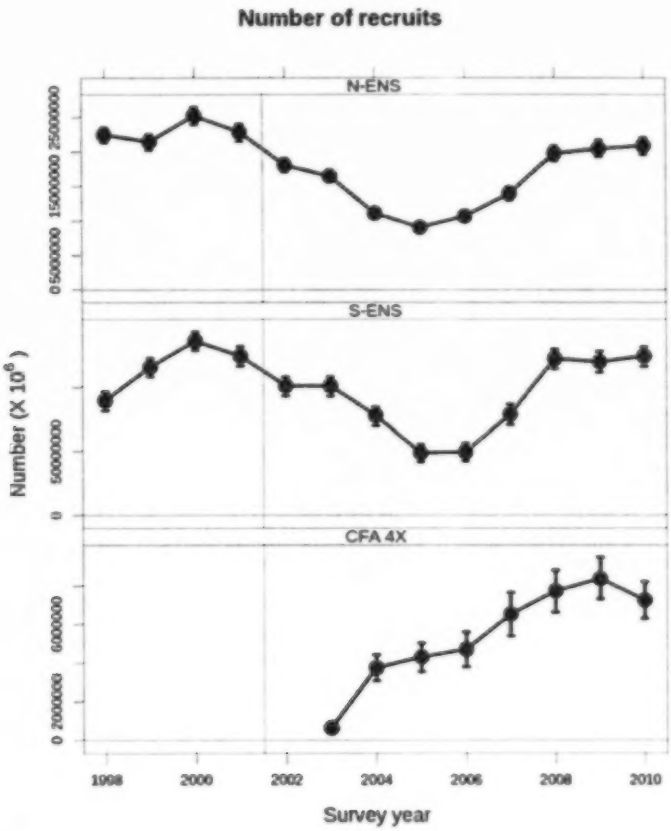


Figure 8. Expected recruitment (males larger than 95 mm CW and soft-shelled) into the mature stage in the next year, with 2 standard errors bars. As surveys are conducted in the autumn (since 2002/2003), the majority of recruitment into the fishable biomass has already occurred. This figure shows the additional recruitment expected that has not yet become part of the fishable biomass. Error bars are 95% confidence intervals about the estimated total biomass.

Reproduction

Female snow crab abundance has continued to decline in all areas but remains above historic means. The associated egg production continues to decline after reaching historic highs in 2007/2008 (Figure 9b, 10). Egg production is expected to begin to decline below historic means due to a lack of immature female crab between 30-60 mm, potentially affecting long-term recruitment patterns. Isolated concentrations of mature females exist in all areas with a more diffuse distribution around the CFA 23 / 24 management line (Maps 6, 7). Sex ratios are continuing to decline (Figure 11).

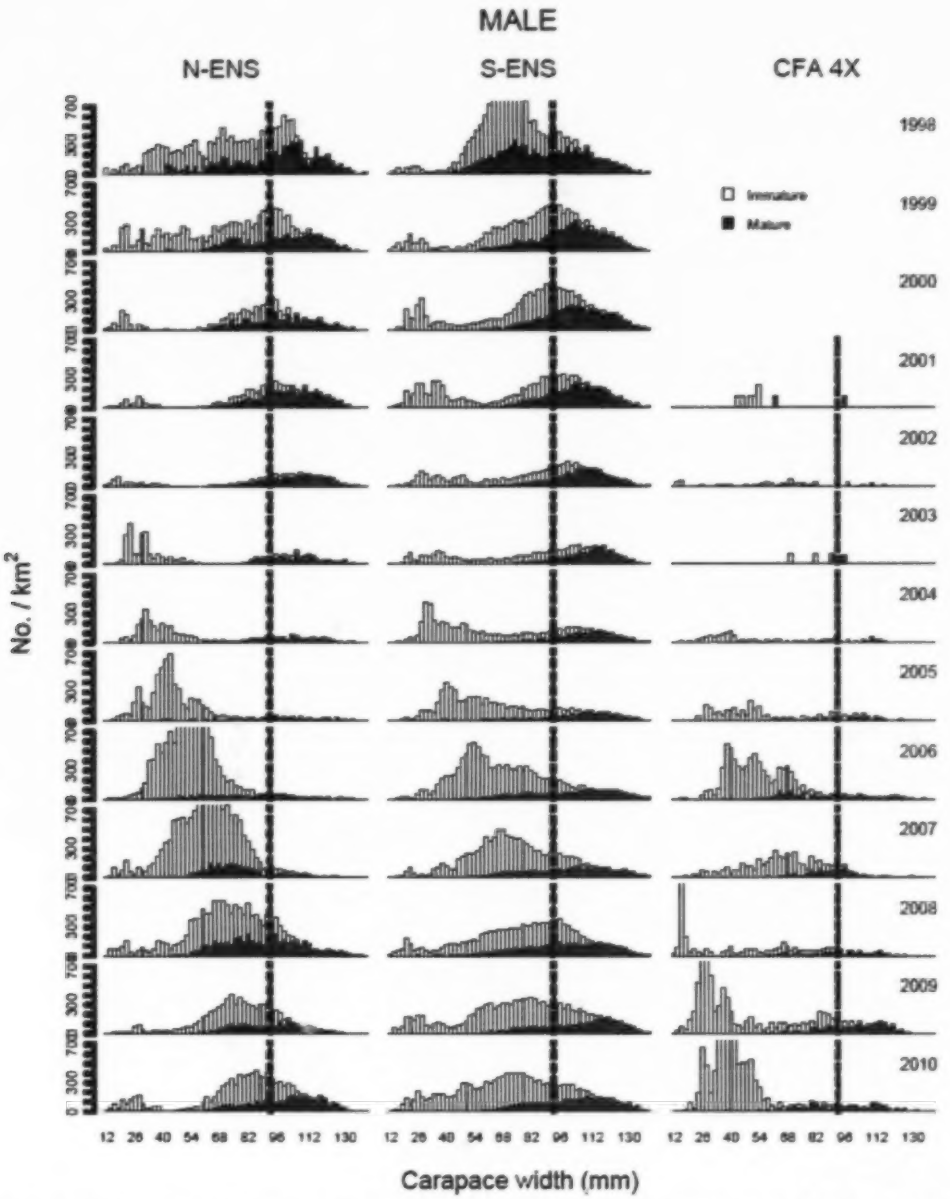


Figure 9a. Size-frequency histograms of carapace width of male snow crabs. Note the relatively uniform distribution of adolescent crab across all size classes in S-ENS as compared to other areas and previous patterns in S-ENS. Note that for S-ENS and CFA 4X (but not N-ENS) the spatial extent of the surveys have changed over time, making a direct comparison of numerical density inappropriate. This figure provides information about the relative numbers within a given year.

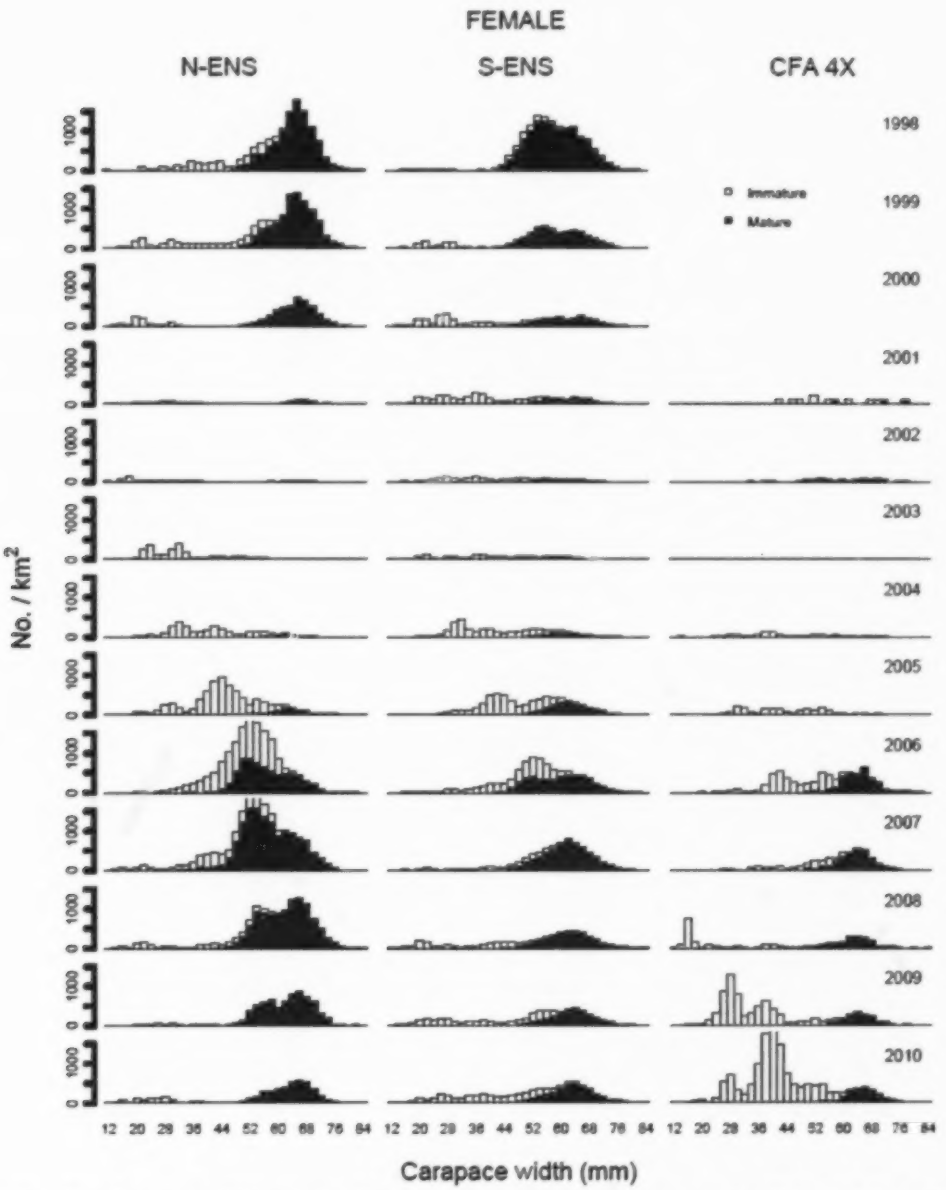


Figure 9b. Size-frequency histograms of carapace width of female snow crabs. Note that for S-ENS and CFA 4X (but not N-ENS) the spatial extent of the surveys have changed over time, making a direct comparison of numerical density inappropriate. This figure provides information about the relative numbers within a given year.

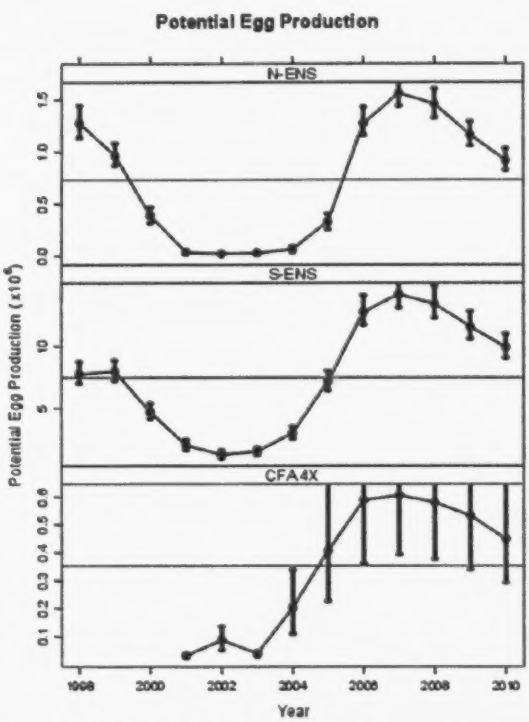


Figure 10. Potential egg production of snow crab on the Scotian Shelf. Vertical line represents the shift in survey timing from spring to autumn.

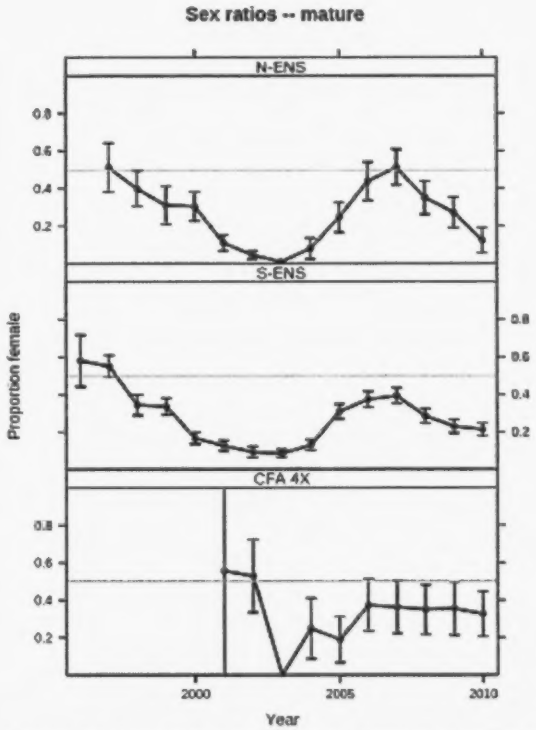


Figure 11. Sex ratios (proportion female) of mature snow crab. Since 2000, most of the Scotian Shelf was uniformly male dominated.

Fishing mortality

The abundance estimates of old male crab (CC5) has been stable in the historical record and below the detection limit on the Scotian Shelf. Their low representation in the survey data and the fishery-observed data may be indicative of high exploitation rates and/or high mortality rates.

Fishing mortality in N-ENS has historically been in the range of 0.1 to 0.5, peaking in 2004 (Figure 12). In 2010, fishing mortality is estimated to have been 0.19 (95% CI: 0.14, 0.24; or a harvest rate of 17.3%), unchanged relative to 2009 (Figure 12). The low fishing mortality in 2008 was implemented to reduce soft-shell handling.

Fishing mortality for S-ENS has historically ranged from 0.05 to 0.25, peaking in 2003-2004 and in 2010 (Figure 12). In 2010, fishing mortality is estimated to have been 0.23 (95% CI: 0.15, 0.33; or a harvest rate of 20.5%); a small increase from 0.20 in 2009. Localized exploitation rates are likely higher as not all areas where biomass estimates are provided are utilised (e.g., continental slope areas, and western, inshore areas of CFA 24). Such localised over-harvesting is a concern because this increases the catchability of soft-shelled crab which leads to greater handling mortality of new recruits into the fishable biomass and also loss of habitat grounds to competitors of snow crab (e.g., other crab species).

In CFA 4X, fishing mortality has historically ranged from 0.2 to 0.45, only declining towards target levels of 0.223 since 2008 (Figure 12). In 2009/2010, fishing mortality was 0.22 (95% CI:

0.15, 0.33; or a harvest rate of 19.7%). In 2008/2009, fishing mortality was marginally lower 0.19. However, due to the very specific spatial extent of the fishery in area 4X, focused primarily upon the area near Sambro and Roseway, realized exploitation rates are likely to be higher, since the computed exploitation rates incorporate biomass from throughout the CFA 4X area.

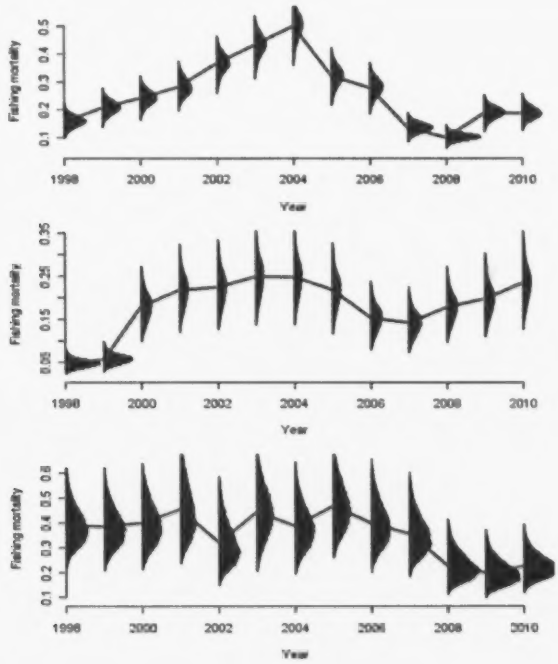


Figure 12. Fishing mortality for NENS, SENS and CFA 4X, respectively.

Ecosystem Considerations

A multivariate summary of key environmental (climatic), social, economic and fishery-related indicators (Figure 13) suggests that a suite of coherent changes have occurred on the Scotian Shelf since the early 1990s. These latter changes include: changes in the relative abundance of groundfish (declining) and invertebrates (increasing; e.g., snow crab) and their associated landings and landed values; socio-economic changes in ocean use such as oil and gas exploration and development (increasing); and Gross Domestic Product (GDP) associated with the oil and gas sector as well as total Nova Scotia GDP (increasing). Further, the physiological condition of many groups of fish has also been declining and the total number of shellfish closures have increased with time, as has the amount of seismic activity. Increasing ocean colour, abundance of diatoms and dinoflagellates, and declining abundance of *Calanus finmarchicus* were also influential to this axis of variation. The temporal differences along this axis of variation indicate that coherent systemic changes of socio-economic and ecological indicators occurred in the early 1990s associated with the groundfish collapse. A trend towards a return to historical states is evident since an extreme point in 2003 (Figure 14). Thus, while the current "ecosystem state" is one that continues to be amenable to the high abundance of snow crab, there is an increased concern that there may be another systemic ecosystem change in the near future. An increase in groundfish stocks would increase predation upon snow crab stocks. Other consequences of such an ecosystem shift could exist for snow crab.

Importantly, temperature-related changes were generally orthogonal (independent) to the above changes, e.g., bottom temperatures and variability in bottom temperatures, bottom oxygen concentrations, and sea ice coverage. The temporal variations of this axis indicate that the current ocean-climate has returned to its average state after a decade-long divergence from the late 1980s to the late 1990s. Temperature anomalies in particular were considered a potential cause of the increase in abundance of snow crab in the late 1990s due to snow crab being cold-water stenotherms. However, the habitat analysis (Figure 15) suggests that potential snow crab habitat existed in the 1970s and 1980s, suggesting that their recent increase in abundance is primarily driven by non-environmental factors such as reduced predation mortality and increased survival of early life stages (see section on Environmental Variability, below).

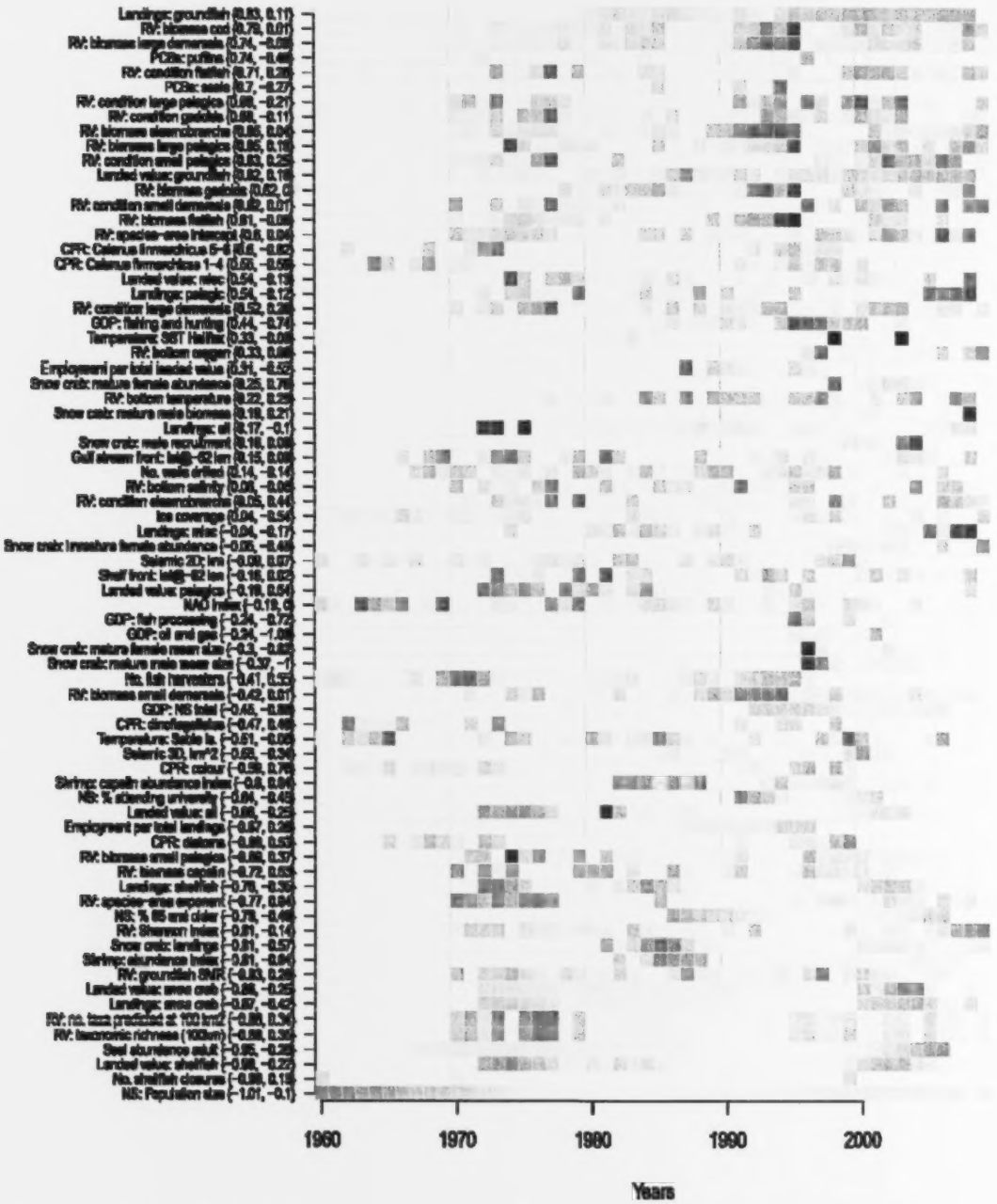


Figure 13. Sorted ordination of anomalies of key social, economic, and ecological patterns on the Scotian Shelf relevant to snow crab. Red indicates below the mean and green indicates above the mean. (Original in colour.)

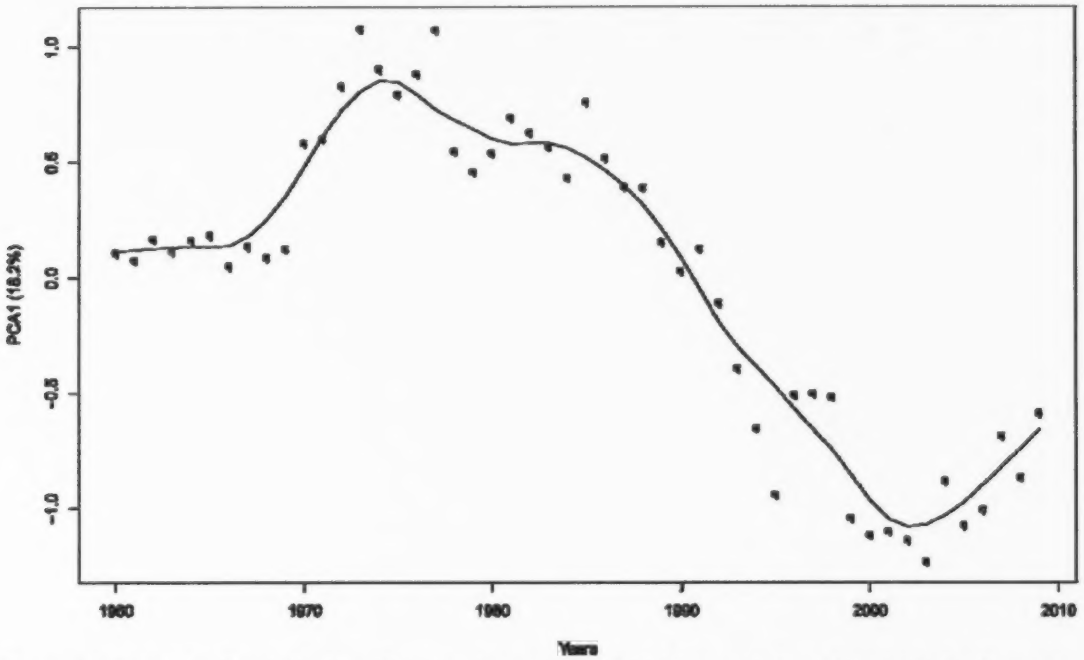


Figure 14: First axis of variation in ordination of anomalies of social, economic and ecological patterns on the Scotian Shelf.

Environmental Variability

The surface area of potential snow crab habitat in the Scotian Shelf Ecosystem (SSE) has been stable in the historical record with an increase since the mid-1980s associated with the groundfish collapse and ecosystem-scale changes (Figure 16a). In N-ENS, the surface area of predicted snow crab habitat has varied between 1.4 to 3.5 × 10^3 km^2 (Figure 16a) with higher levels than the historical mean of the habitat area in 2010. For S-ENS, the surface area of potential habitat has varied with similar oscillations, ranging from between 25 to 44 × 10^3 km^2 with higher levels than the historical mean of the habitat area in 2010. In CFA 4X, the southern-most limit of the distribution of snow crab, potential habitat has been highly variable, ranging from 0 to 2.2 × 10^3 km^2, with an historical maximum in 2009/2010.

As can be seen, temperature variations had little to do with this increase (Figure 16b). Average bottom temperatures in 2010 were generally similar to those in 2009. Within the area that may be considered potential snow crab habitat, average bottom temperatures were generally quite stable: 3.2, 3.3 and 6.2°C in N-, S-ENS and CFA 4X, respectively (Figure 16b). Average bottom temperatures in 2010 were generally close to the long-term means, especially in CFA 4X. Bottom temperature variations have been mostly in phase throughout the three sub-areas in the historical record.

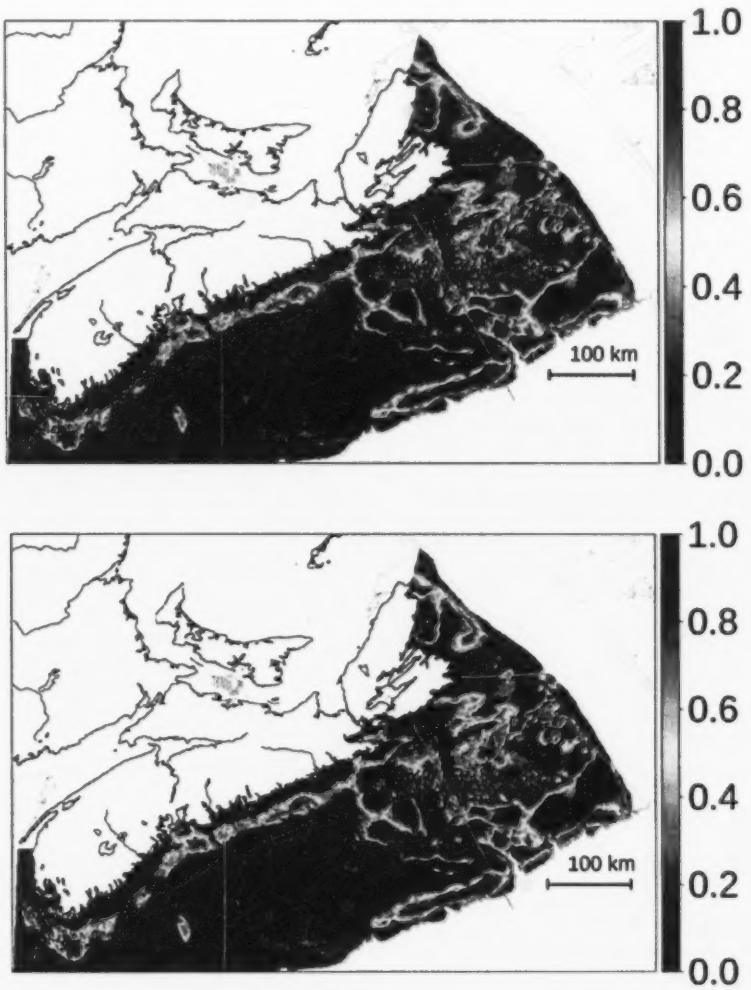


Figure 15. Predicted probabilities of viable habitat for fishable snow crab, or "habitat mask", used for abundance estimation. (Original in colour.)

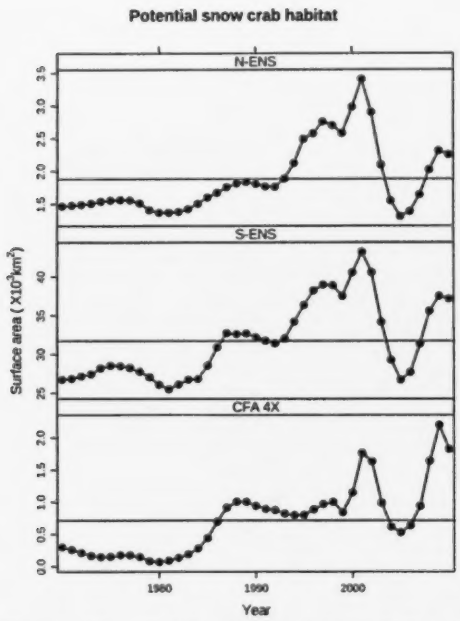


Figure 16a. Total surface area of the potential habitat space of snow crab

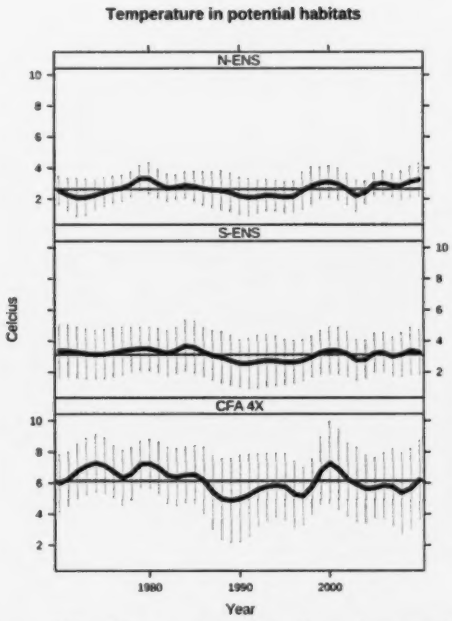


Figure 16b. Mean annual bottom temperatures within the potential habitat space of snow crab.

Bottom-up (Resource Limitation)

Food items such as northern shrimp are found in concentrations comparable to the historical average in most core areas of S-ENS (based on snow crab trawl survey; Map 8).

Near the ocean surface, there has been a trend towards increased ocean colour, which is an index of chlorophyll concentrations. Therefore, total primary production may be increasing (in the form of diatoms and dinoflagellates). This is likely enhanced by the reduction in abundance of *Calanus finmarchicus,* an important zooplankton link in the pelagic food web. Whether this elevated primary production reaches the detrital system is not yet known.

Top-down (Predation)

Predators of immature and soft-shelled crab were found in high relative densities (based on snow crab trawl survey) in areas with high densities of immature snow crab (For example, thorny skate - Map 9). This adds uncertainty to the potential strength of recruitment to the fishable biomass.

Seals are considered by fishers to be a potential predator of snow crab, and their continued increase in abundance (Figure 13) is a source of concern for many fishers and some scientists. While seals have been observed with snow crab in their stomachs, it should also be emphasized that high concentrations of snow crab are currently found in the immediate vicinity of Sable Island, an area where the abundance of grey seals is extremely high. The evidence indicating that seals have a negative influence upon the snow crab population, therefore, seems to be minimal. In fact, it is quite possible that seals may be having a positive influence by physically importing food and food waste (organic matter) from other more outlying areas to the immediate vicinity of Sable Island. This would indirectly "feed" the snow crab and also protect them from potential predators of crab (in both early pelagic and benthic stages).

Lateral (Competition)

Large mature males stabilize the snow crab population by maintaining and occupying prime crab habitat. Large mature males keep at bay potential competitors such as other crab species or even groundfish, serve as strong mates for the current population pulse of mature females, and are protectors of the smaller females. Their over-exploitation can have numerous negative biological consequences.

An important consequence of the extended period of low numbers of females to males (Figure 11) observed in the early-2000s throughout the Scotian Shelf is that poor egg and larval production in the system likely occurred for at least a four to five year period. Poor egg production may occur again in the mid 2010s. Stabilisation of such strong oscillations in abundance into the future may be possible if reproduction of the currently available females is supported by an adequate population of large males.

Human Influences

Oil and gas development/exploitation continues to occur on the Scotian Shelf near to, or upstream of, major crab fishing grounds and population centers in both N- and S-ENS. The effects of seismic methods of exploration upon potentially vulnerable components of the snow crab population (eggs, larvae, soft-shelled crab) and the long-term biological effects of development upon this long-lived species are still not known (DFO 2004). Despite such uncertainties and objections from the fishing industry, DFO Science and NGOs (Boudreau et al. 2009), seismic exploration occurred in November 2005 and July 2010 immediately over the Glace Bay Hole and the shallows of the Sydney Bight (Hunt Oil 2005) where immature and female crab are generally abundant. Due to a concern that the low abundance of snow crab in the Glace Bay Hole area may be related to these activities, even with no exploitation of the area, further investigations have been requested. Other seismic studies occurred Husky Oil, in July 2010 also conducted additional seismic studies over the Sidney Bight (Husky Oil 2010). Artimon Bank, Banquereau Bank and the Stone Fence in 2009 and 2010 (RPS Group/Dalhousie).

By-catch levels, mostly of other crustacean species, have been extremely low in the historical record. In ENS, less than 0.014% of 2010 landings are non-targeted species, while in CFA 4X, it was 0.17% of landings. The majority of by-catch is composed of other invertebrate species (e.g., Jonah crab and American lobster). All by-catch is returned to the water by snow crab fishers, generally in excellent condition. In 2010, at-sea observers also reported a leatherback sea turtle as having been entangled in buoy lines. This turtle was released though the animal was observed to be bleeding.

By-catch of snow crab from other fisheries is still not quantified. Trawls can increase mortality, especially upon the soft-shelled phases of snow crab, though the lack of trawl fisheries (other than shrimp trawling) in the majority of snow crab habitat on the Scotian Shelf limits this potential damage. Bottom damage from the placement of snow crab traps is thought to be minimal.

CONCLUSIONS AND ADVICE

Potentially high catches of soft-shelled crab might be an issue for the next 2 to 3 years in N- and S-ENS (but not CFA 4X due to their offset fishing season), depending on spring or summer

fishing activities. Timely responses from industry to avoid fishing in areas showing potential or actual high incidence of soft crab must continue if unnecessary mortality of future recruits is to be averted. An earlier season in N- and S-ENS appeared to significantly reduce soft-shell handling and is encouraged to be continued in 2011 and future seasons.

Fishing mortality in N-ENS was estimated to be 0.19 (95% CI: 0.14, 0.24) or a harvest rate of 17.3%, unchanged relative to 2009. Good recruitment and a significantly reduced soft-shell handling results in a positive outlook. Until a strong and persistent increase in fishable biomass is observed, maintaining long-term harvest rates between 10% and 20% is part of the strategy for sustainability in this fishery. A decreased or status quo harvest strategy is recommended.

Fishing mortality in S-ENS was estimated to be 0.23 (95% CI: 0.15, 0.33) or a harvest rate of 20.5%, a small increase relative to F=0.0.20 in 2009. Good recruitment suggests a positive outlook; however, the capture of soft shell crab remains an important issue for this fleet. Long-term harvest rates between 10% and 30% is part of the strategy for sustainability in this fishery. A decreased or status quo harvest strategy is recommended.

Fishing mortality in CFA 4X for 2009/2010 was estimated to be 0.22 (95% CI: 0.15, 0.33) or a harvest rate of 19.7%, relative to F=0.19 in 2008/2009. Long-term harvest rates between 10% and 30% is part of the strategy for sustainability in this fishery. As recruitment into the 2011/2012 season is uncertain, a decreased or status quo harvest strategy is recommended.

MANAGEMENT CONSIDERATIONS

The prompt and careful return of immature crab to the water by the fishery is an important conservation measure that will enhance the mid-term (2-3 year) sustainability of this fishery. This is a measure that needs to contine.

The DFO is moving to formalize the Precautionary Approach policy and framework for key harvested stocks managed by Fisheries and Oceans Canada. The primary components of the framework are:

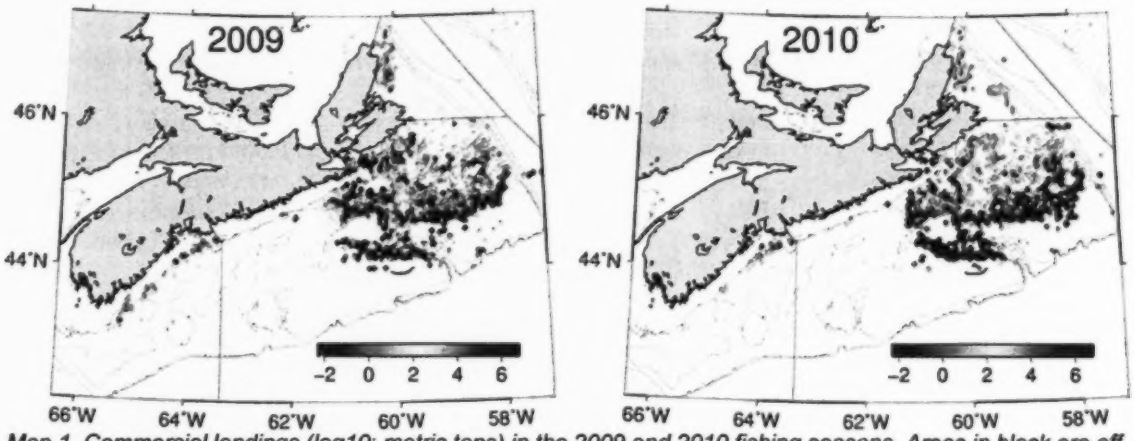
1. Reference points and stock status zones (Healthy, Cautious and Critical).
2. Harvest strategy and harvest decision rules.
3. The need to take into account uncertainty and risk when developing reference points and developing and implementing decision rules.

Current assessments indicate the snow crab fishery will likely be defined as being in a healthy state with respect to the Precautionary Approach framework. Harvest control rules and strategies currently in place (and pre-dating the Precautionary Approach policy by many years) are designed to maintain this condition and promote long-term sustainability. Uncertainties are accounted for when providing management advice. As a result, many of the requirements of the DFO Precautionary Approach Policy are already well established:

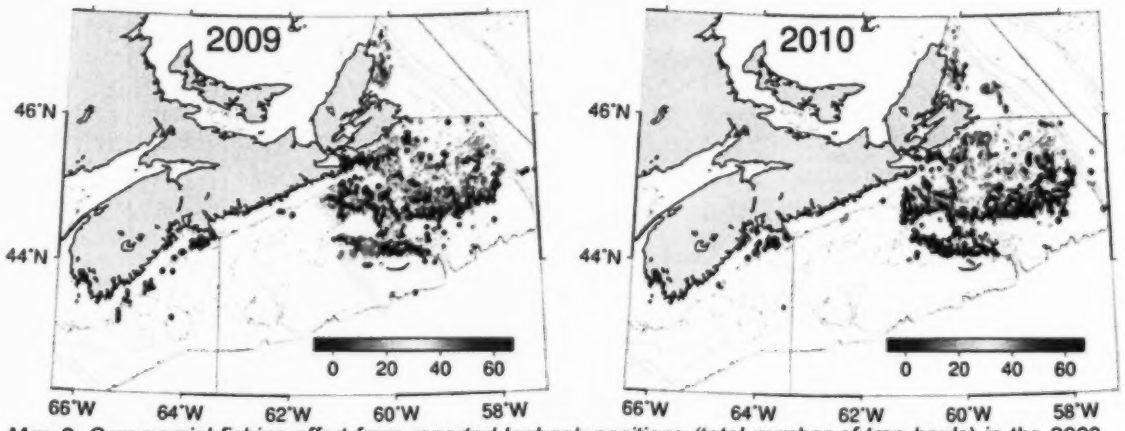
The snow crab fishery as a male-only fishery that targets post-reproductive males has a built-in protection mechanism for the spawning stock biomass. As such, it can be considered Precautionary Approach compliant. Further, the very low exploitation strategies applied on the SSE relative to other areas in the Northwest Atlantic renders it Precautionary Approach compliant, over and above DFO's interpretation of the Precautionary Approach (DFO 2006). Detailed information on recruitment, reproductive potential and adaptive management measures to control handling mortality and by-catch mortality, in addition to information of ecosystem

context and traditional stakeholder knowledge help determine the health of the snow crab populations to ensure even more compliance.

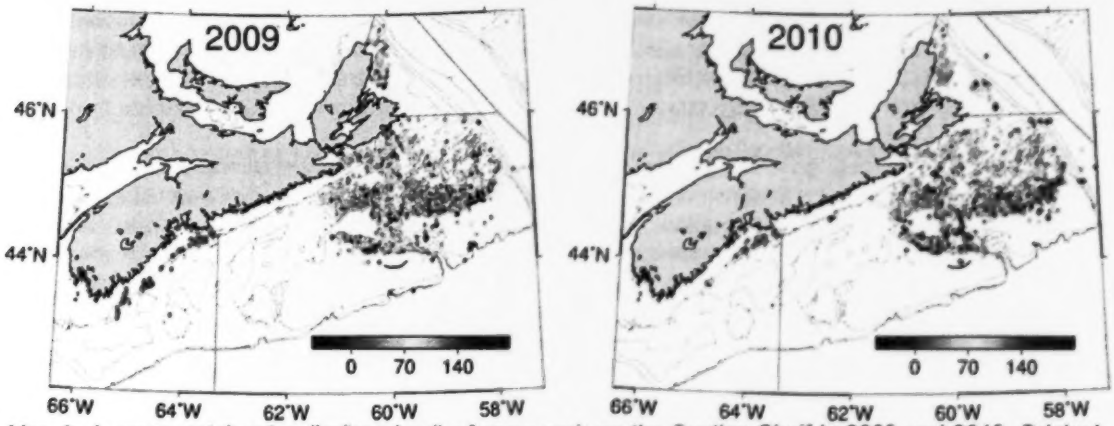
Next steps include Fisheries Management, the Fishing Industry, and Science to work together to define reference points, stock status zones, and develop the bases for harvest strategies in each zone. To assist in the completion of these steps, Biomass at Maximum Sustainable Yield (B_{MSY}) has been identified for each management area - N-ENS, S-ENS, and 4X.



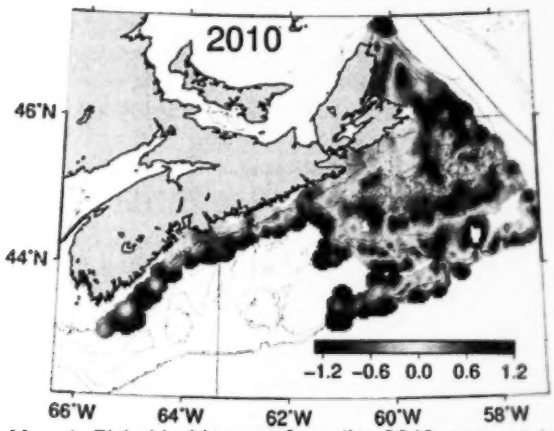
Map 1. Commercial landings (log10; metric tons) in the 2009 and 2010 fishing seasons. Areas in black are off the scale. Original figure in colour.



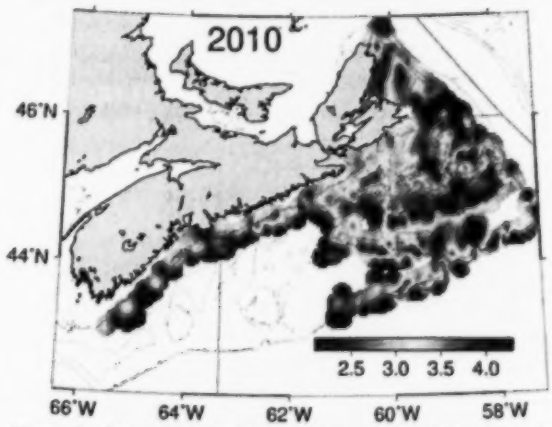
Map 2. Commercial fishing effort from reported logbook positions (total number of trap hauls) in the 2009 and 20010 fishing seasons. Note the shifting of effort away from inshore areas in S-ENS. Areas in black are off the scale. Original figure in colour.



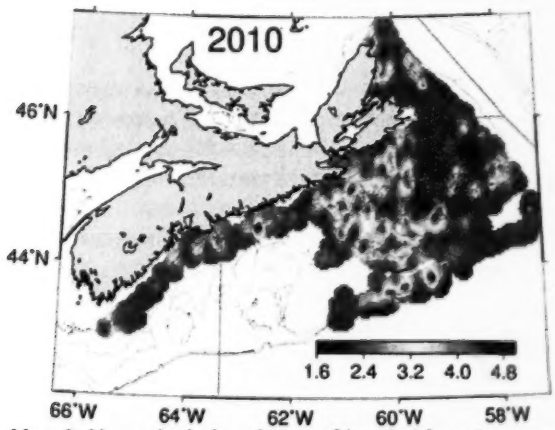
Map 3. Average catch rates (kg/trap haul) of snow crab on the Scotian Shelf in 2009 and 2010. Original figure in colour.



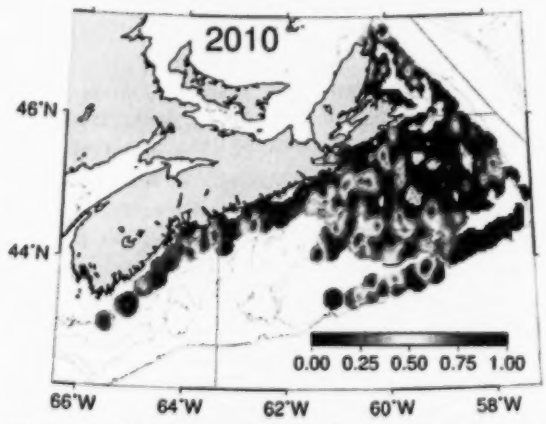
Map 4. Fishable biomass from the 2010 snow crab survey. Log 10 scale. Original figure in colour.



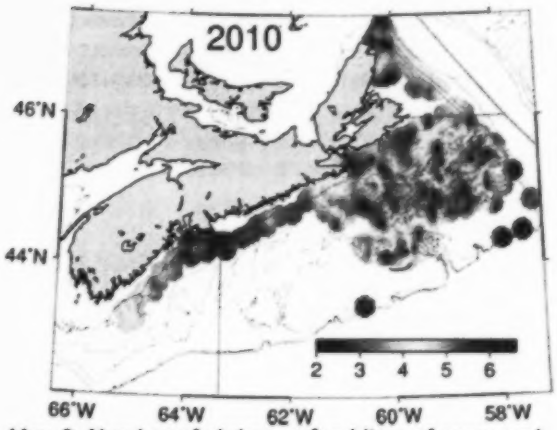
Map 5. Numerical abundance of recruitment of snow crab in 2010. Log 10 scale. Original figure in colour.



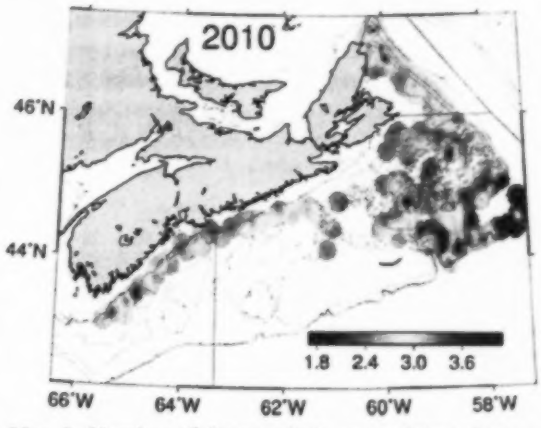
Map 6. Numerical abundance of berried female snow crab. Log 10 scale. Original figure in colour.



Map 7. Proportion of females in the mature population. Note the heterogeneous distribution of sexes in all areas. Original figure in colour.



Map 8. Number of shrimp, a food item of snow crab. Log 10 scale. Original figure in colour.



Map 9. Number of thorny skate, a predator of snow crab. Log 10 scale. Original figure in colour.

SOURCES OF INFORMATION

This Science Advisory Report is from the Fisheries and Oceans Canada, Canadian Science Advisory Secretariat, regional advisory meeting of 1-2 March 2011 on Atlantic Nova Scotia Snow Crab Assessment Additional publications from this process will be posted as they become available on the DFO Science Advisory Schedule at http://www.dfo-mpo.gc.ca/csas-sccs/index-eng.htm.

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